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STATE SCHOOL OF MINES BULLETIN

NUMBER 2

MARCH, 1909

TESTS
OF
MACADAM ROCK

BY

E. H. BECKSTRAND

BULLETIN No. 2 OF THE STATE SCHOOL OF MINES
UNIVERSITY OF UTAH

SALT LAKE CITY, UTAH

What Is the State School of Mines?

The State School of Mines is the college of engineering of the University of Utah. It is an organic part of the University and enjoys all the advantages that spring from an intimate connection between a technical college and a modern university.

COURSES.

The school offers seven four-year courses leading to bachelor's degrees, also graduate courses leading to the degree of master of science in several lines of engineering. The seven four-year courses are in MINING ENGINEERING, ELECTRICAL ENGINEERING, CIVIL ENGINEERING, MECHANICAL ENGINEERING, CHEMICAL ENGINEERING, GENERAL ENGINEERING, and IRRIGATION ENGINEERING, the first part of the course in irrigation engineering being given, however, by the Agricultural College at Logan. Graduate courses are offered in each of these lines of engineering.

FACILITIES AND EQUIPMENT.

The school is provided with a first-class equipment to do its work. The laboratories are all well furnished, in this respect ranking with the foremost colleges of the country. The teachers are all specialists and the methods of instruction modern. For mining work the location of the school is unexcelled, Salt Lake City being the center of a great mining region, which makes it easy to provide abundant and inexpensive field work.

EXPENSES.

The expenses at the school are very low, the cost of registration and tuition being from ten to twenty-five dollars per year. The school is perhaps the most inexpensive good engineering college in the country for a student to attend.

Catalogues and illustrated circulars are sent free on request.

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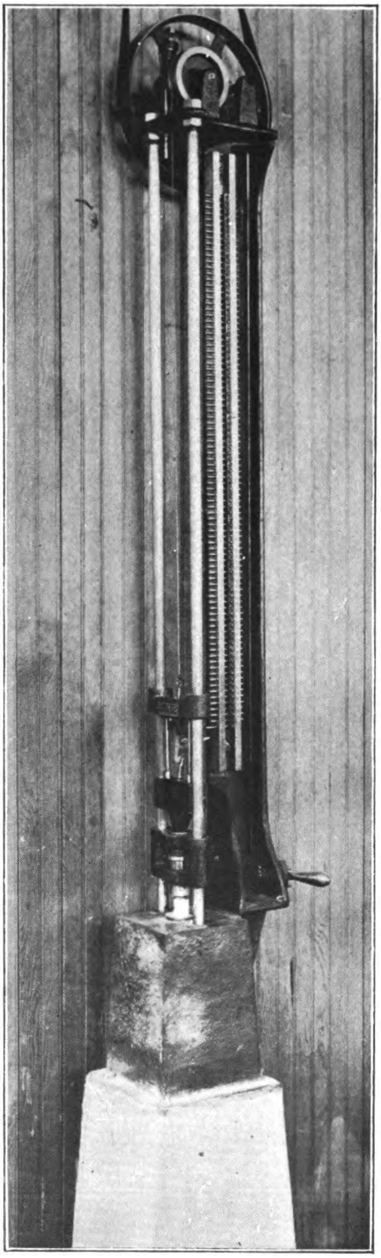

Fig. 3.
Impact Testing Machine for testing the toughness of macadam rock and also for testing the recementing value of rock dust.

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ANNOUNCEMENT

Salt Lake City, Mar. 18, 1909.

The Governor and Legislature of the State of Utah have just established the **Utah Engineering Experiment Station** "in connection with, and as a department of the State School of Mines," the engineering college of the University of Utah.

The Station is placed under the management of the Regents of the University, and they are required to appoint a Station Staff consisting of the Director and Heads of Departments of the State School of Mines.

The Station is "authorized to carry on experiments and investigations, pertaining to any and all questions and problems that admit of laboratory methods of study, and a solution of which would tend to benefit the industrial interests of the State, or would be for the public good, or would add to the sum of human knowledge;" provided, that the Station be not "authorized to concern itself with problems that properly belong to the Experiment Station of the Agricultural College of Utah."

In accordance with the provisions of the bill establishing the Station, the Regents will proceed at once to organize the station staff, who, in turn, will outline the work that the station is to undertake in the immediate future. Future bulletins of the State School of Mines, similar to this one, will be published as Bulletins of the Utah Engineering Experiment Station.

JOS. F. MERRILL,
Director, State School of Mines.

INTRODUCTORY NOTE

The work on the present bulletin was begun partly in conjunction with and agreeably to the desires of the Salt Lake City Engineer's office. Heretofore, there have been no machines for testing stone for macadamizing purposes in the State, and to enable road engineers to intelligently select material, the School of Mines installed a road testing laboratory in which series of tests will be made on available stone for road building purposes.

The samples for this series of tests were collected by a representative from the City Engineer's office, and by a representative from the testing laboratory force. Samples were taken at places indicated by Prof. E. H. Beckstrand, and by the City Engineer. About 100 pounds of stone, representative of the quarry, was taken and as much as necessary was used.

The present publication is sent out for the purpose of showing how such materials are tested, and to give a series of comparative results on various rock treated the same way.

These few tests are only introductory to the work that should be carried on in the different parts of the State where such information is needed.

The experimental work was done mainly by Mr. R. R. Woolley, B. S. (M. E.), 1908, to whom due acknowledgment is made.

For copies of bulletins, circulars, or other information, address the State School of Mines, Salt Lake City, Utah.

UNIVERSITY OF UTAH
DEPARTMENT OF
Mechanical Engineering and Testing of Materials

BULLETIN No. 2 MARCH, 1909

THE TESTING OF MACADAM ROCK BY STANDARD LABORATORY METHODS

BY E. H. BECKSTRAND, PROFESSOR OF MECHANICAL ENGINEERING AND APPLIED MECHANICS, MEMBER OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS AND MEMBER OF THE AMERICAN SOCIETY FOR TESTING MATERIALS

It is well known to the people of the State of Utah, that we have been spending vast sums of money in the form of cash and labor, in the construction, care and maintenance of the public roads of this State. It is generally conceded that much of this money has been spent in such a way that much has been wasted, through lack of intelligence on the part of the supervisor. This is hardly to be wondered at when we consider the state of knowledge of our best engineers as to the relative value of the different stone available for road-building in the State.

The State of Utah and surrounding States are provided with rock of nearly every variety that could be desired for road building, and most in sufficient quantities, as well as being situated accessibly, so that it could be used in road building. There are found in the foothills ledges and quarries of many kinds of rock, such as limestone, quartzite, granite, trap, sandstone, a large variety of pure igneous, as well as many other kinds of rock, surrounding every town, and accessibly situated, so that every road could be improved with a minimum cost for transportation.

Naturally, the most important roads in and leading to the larger cities will and are receiving first attention. When it has been decided to improve a road or street, several important matters come up for consideration:

1. What shall be the nature of the improvement? Shall the road be graded and drained only, or shall it be graded, drained and graveled, or shall it be covered with some form of pavement? 2. In case macadam pavement is decided upon, then the question of vital importance to the engineer is the deciding of which of the available rock is the best to use. This is a technical engineering question, and can only be settled properly by knowing the amount and kind of traffic the road is to carry, and the physical proper-

ties of the various stone available for use. It is well known that a soft rock is satisfactory for some kinds of traffic, while it would be entirely unsatisfactory for a heavy traffic, a heavy traffic requiring a harder and tougher stone. After the amount of traffic has been estimated by the engineer, it is then his duty to choose from the available rock, one which will be able to cary the traffic with not too great a wear, so that mud will result in winter, and a great amount of dust in summer, nor one with too little wear, so that all the fine dust will be blown away, leaving the stone uncovered. The adaptability of any rock for road building can only be known by a series of physical tests being made on the various available quarries, and then by comparison of the results of the tests, an intelligent selection can be made.

Necessity for a Road Testing Laboratory in the State.

Because on certain roads limestone has proved to be successful in carrying the traffic, is no reason for concluding that all limestone is good for road building. On the contrary, the tests on some limestone show good wearing quality, ample hardness, and toughness, and excellent binding and recementing qualities; while the tests on other limestone taken in the same vicinity, and apparently the same kind of rock, show entire lack of many of the necessary physical characteristic qualities for a good road metal. The only ways to prove that a rock quarry contains the essential qualities making it adaptable to the wear it will be subjected to is to—1, test the rock for its physical properties, or, 2, use the rock on the road and await results. Intelligent road engineering can only be gotten by studying the results given by the testing laboratory. Many times it has proven most expensive to use a product —asphalt, cement, or stone—in road building without knowing its properties.

It is to guard against these errors and to make the selection of materials used in engineering construction more intelligent, in which the public is interested directly, that caused the Utah State School of Mines to install a road testing laboratory.

Physical Properties that Are Desirable in Rock for Road Building.

In order to decide what physical properties a road building rock should contain, it is necessary for us to inquire into the wear that rocks are subjected to. They are: 1. The grinding action of the tires of vehicles. 2. The impact of the vehicles, and horses' feet, at rapid speed. 3. The distintegration from the elements—frost, rain, and wind. It is well agreed among engineers that the best macadamizing rock for a road is one that is hard enough to resist excessive wear, permitting only enough wear to replace the fine dust washed away by rain or blown away by wind. It should be tough enough so that it will resist the impact coming upon it without breaking continually into smaller pieces. When ground

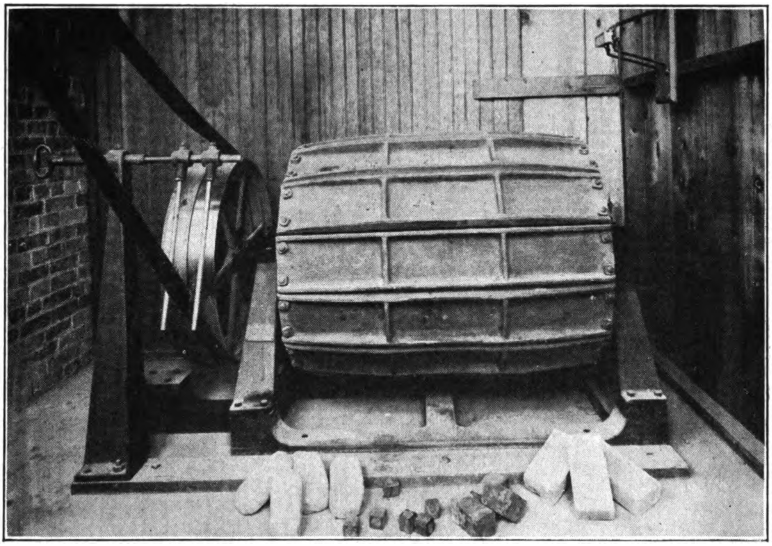

Fig. 1
Abrasion Cylinder for testing the wearing quality of paving brick and paving stone.

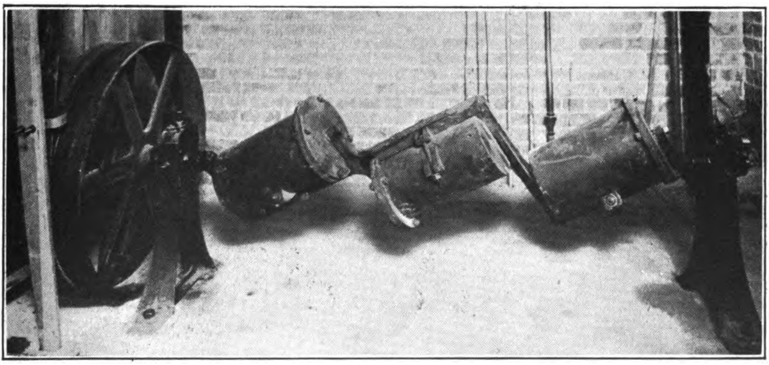

Fig. 2
Abrasion Cylinders for testing the wearing quality of macadam rock.

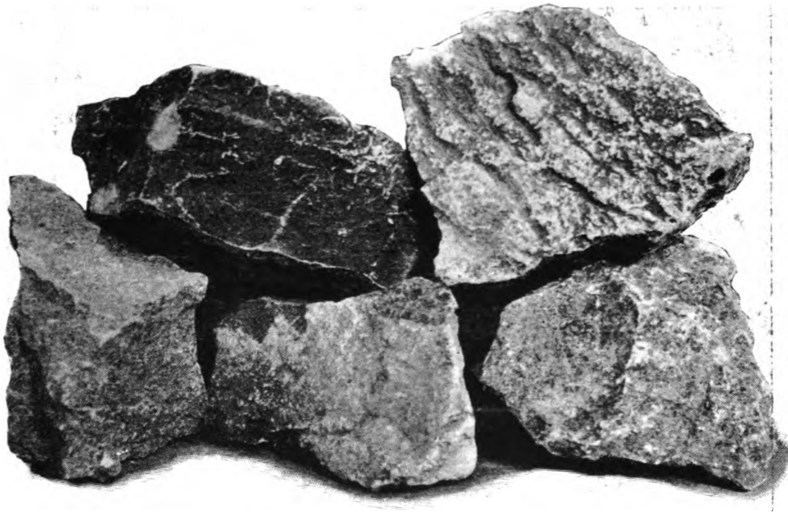

Fig. 4
Standard size pieces of Limestone before testing in abrasion cylinder for wear.

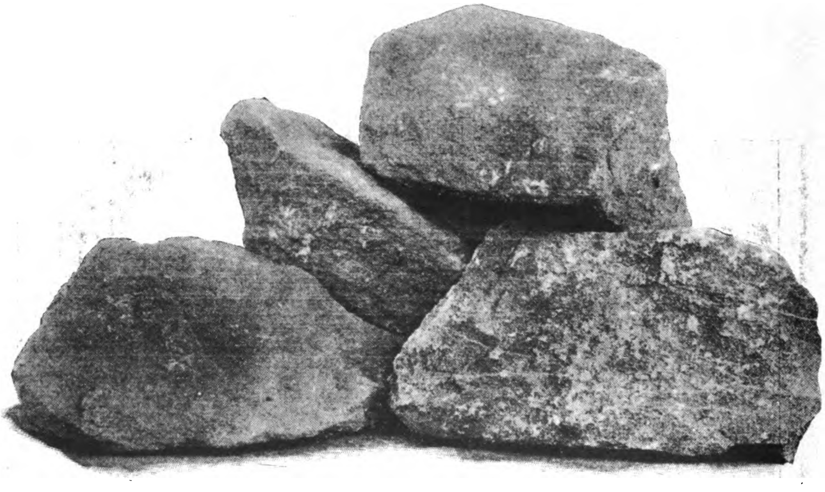

Fig. 5
Limestone after wearing test in abrasion cylinder.

to a fine dust and pressed into the interstices of the larger pieces, it should recement well, thus forming a binder for the larger pieces. When a rock is too soft. too much dust is formed and the road is soon surfaced with a coat of mud in winter and dust in summer; when it is too hard, not enough dust is produced, thus gravel and pieces of rock project through and are soon loosened, admitting water into the foundation. The problem, then, is to find materials with properties such that they will best withstand the wear and climatic conditions. This can be done best and only by determining the hardness, wearing quality, toughness, recementing quality, the mineral compositions, shown by the microscope, the heaviness and the absorption capacity for water, of all available rock, and choosing from among them the one that shows satisfactory laboratory results. While the relative cost of rock from different localities enter into the problem as an important consideration, it should not be the deciding factor, but the adaptation of the rock to the road to be built as measured by the heaviness of the traffic and physical tests should be the important factor, with cost secondary.

Standard Tests for Determination of Physical Properties.

Making systematic tests on materials to be used as a road metal was first done in France. The French engineers first recognized the difference in the wearing quality of the different rocks when placed on the surface of roads, and devised several tests to be made on the rock which would enable a comparison of the durability of different kinds of stone to be made. These tests are an abrasion test, to determine the wearing quality, an impact test to determine the toughness of the stone, a grinding test to determine the hardness, a test on the cementing value of the rock dust is also often made. Microscopic slides of rock sections are made to determine the mineralogical composition of rock, per cent of absorption of water is useful to compare the probable action of frost. Some of the machinery for making these tests, as well as some of the products, are shown in the accompanying cuts.

The standard abrasion test as adopted by the American Society for Testing Materials requires 30 pounds of coarsely broken stone to be available, and that there shall be placed in the cylinder as nearly as may be, 50 pieces weighing 11 pounds. The cylinder, as shown in the cut, is placed at an angle of 30 degrees with the axis of rotation. The cover on the cylinder being tight fitting, the material is thrown from one end of the cylinder to the other, this continuing for 10,000 revolutions at the rate of 30 to 33 per minute. At the end of the test the worn material is the part which is fine enough to pass through a sieve having 1-16-inch mesh. The per cent of wear may be used in comparing different materials or the French coefficient of wear, which is 400÷W. W is the weight in grams of detritus under 1-16-inch per kilogram of rock used.

In the standard impact or toughness test, cylinders or cubes of the rock are made .985 inch in diameter and the same in height. These test pieces are placed on an anvil weighing 10 kilograms, with a cylinder of steel bearing on the top weighing 1 kilogram. A hammer weighing 2 kilograms is then dropped on the intervening plunger from a height of 1 centimeter for the first blow, two for the second, and so on until fracture occurs. The number of blows is a gauge of the toughness of the rock.

The recementing value of the dust is made by grinding the rock into a fine dust, moistening it into a very stiff dough, putting it into a mould of the same size as in the toughness test and putting a pressure of 1080 pounds on the surface. The test piece is taken out of the mould and allowed to dry, it being then put in the impact testing machine, and a 1 kilogram hammer dropped on it from a height of 1 centimeter until it breaks down. The number of blows shows the relative cementing quality of the dust. These results on a sample of rock along with the mineralogical composition, the amount of water it will absorb, hardness, and specific gravity, will enable an engineer to choose a suitable and desirable rock for the road he is ready to construct. The selection of the stone is one of the most important preliminary steps to be taken by the engineer in constructing and surfacing a road.

What Should Guide in Accepting or Rejecting Stone.

In discussing this topic I can do no better than to quote from a recent paper by R. S. Greenman, in Transactions of the American Society for Testing Materials, Vol. VIII, page 568. Speaking of New York State, he says: "The great State of New York has become well established in the construction of fifty million dollars' worth of new roads. Experience has already taught that greater care must be taken in the selection of the road metal. * * * The real question before us is not to make tests and secure comparisons, but, having secured the results, how to draw limitations in the selection of stone that will be fair to both the State and producer. In other products we have standard requirements, but in this field we have yet to develop just limitations. Based on standard tests it would be practically impossible to draw up a general specification that would permit the use of a good limestone, and that would at the same time shut out a poor trap-rock or a poor syenite.

"It may be necessary that in each case local conditions shall first be considered and then a specification made to fit these conditions. With a large amount of roads about to be constructed, this probably would not be entirely satisfactory, so if specifications can be drawn covering general conditions and applying to the general classes of road construction, better results must be the outcome of such specifications. For the purpose of discussion it may be well to divide the roads into three general classes: Those of first class or grade, will be those that are 'interurban' or 'trunk lines' which are subject to heavy traffic and wear and which shall be made the best possible, with cost a subordinate consideration; the roads of the second grade will be such roads as are subject to the traffic of an average popular country road, and which shall be constructed with due consideration to both wearing qualities and cost; and the third grade roads will be those which have the ordinary country use and of which the cost of construction and maintenance shall be kept as low as possible. * * *

"If a positive requirement in the results of the tests is to be made we would scarcely wish to accept a stone for use that would not show at least a coefficient of wear of 15, a hardness of 16, a toughness of 13, and a cementing value of 25. We should expect that a good stone would show far better results in some tests than the figures given, but it would not fall below in any one of the tests.

"For a second grade road the requirement should take a much more liberal character. In constructing a road of this grade cost would be a much more important item and the natural desire would be to use the best local stone; but if the quality of the road is to be maintained, it will probably be necessary in a majority of cases to import a desirable stone. It is for this grade that there should be a wide range in the limitations, and yet the minimum requirements should be severe enough to shut out a decidedly inferior stone. We would not want to accept a stone that would not give results of at least 10 for coefficient of wear, 14 for hardness, 10 for toughness, and 20 for cementing value.

"A road of the suggested third grade could be built of any local stone that might be obtainable as long as it had any of the needed qualities of the road metal. The few limitations could be just severe enough to shut out any stone that had weathered badly or had not shown any merits for use as a road stone."

It is well known that the stone made up of certain minerals give better satisfaction and service in roads than other minerals. A study of the composition of the rock can best be made by making a microscopic slide of a rock section and examining it under the microscope to determine the arrangement of the minerals and consequently properly classify the rock.

The test for hardness is a grinding test, made on a small cylinder of rock cut from a larger stone. The end of this cylinder is pressed on to a revolving plate, on which is placed emery dust. The amount worn off by 1000 revolutions of the wheel is a measure of its hardness. The laboratory has as yet no machine for making this test, and therefore hardness tests had to be omitted.

An examination of the accompanying tables, giving the results of tests, will show that there are many ledges and quarries of rock that do not come up to the above standards, while many others give results entirely satisfactory. It is impossible to tell by mere inspection, whether a rock will come up to the requirements to be made of it or not.

Discussion of the Results of Tests.

For the purpose of studying the properties of stone, in the vicinity of Salt Lake City, and comparing their good and bad qualities, which would either recommend them or reject them as rock for road building purposes, the writer undertook a series of tests on the various limestones, quartzites, sandstones, shales, etc., which would be available for road building. It is not claimed that these few tests adequately cover the number and kinds of available rock for road building, on the contrary, it is only a beginning. None, for example, of the igneous rock which are so abundant in the central and southern part of the State have been tested; and many of these are considered the best rock for road building. A few limestone quarries have been tested to show the difference between the results obtained on apparently the same kind of rock.

Examining tables No. 1, 2, 3 and 4, test No. 1 shows a fairly good limestone, having a coefficient of wear of 12, and a toughness of 13 and a cementing value of 27, with small absorption of water and small loss from alternate freezing and thawing, therefore, possessing good weathering qualities. Sample No. 2 was taken from the City quarry, the stone from which Second Avenue was macadamized. This stone shows a coefficient of wear of 3.5, a toughness of 7, cementing value of 3, loss on freezing and thawing of 1.24 per cent. The tests show a lack of the essential properties in a good road building rock. No. 5 shows good wearing qualities, but lacks in other essential qualities. No. 9 is from the Fort quarry, from which the government road was built. The tests on this rock show fair results. No. 12 is a good limestone, showing good wear, toughness and fair comparative cementing property, but not so good weathering quality. No. 15 is another fairly good limestone. It is seen from these results on limestone that there is a wide variation in the results of tests made on apparently the same kind of rock. It would be quite impossible for an engineer to decide between these limestones from mere inspection. The limestones are, perhaps, as variable as any class of rock in their properties, some of them being very good road metals, while others are worthless.

Of the different shales tested, the comparative results show that they are lacking in most of the essentially good qualities necessary in a road building rock.

The sandstones, as we would almost expect, are poor and useless as rock from which to build a road for heavy traffic. They are soft and show great relative wear, and do not weather well. The tests on this class of rock were made for the purpose of comparing the results obtained from material we know to be poor with that which we believe to be good.

The quartzites are quite universal in showing large coefficients

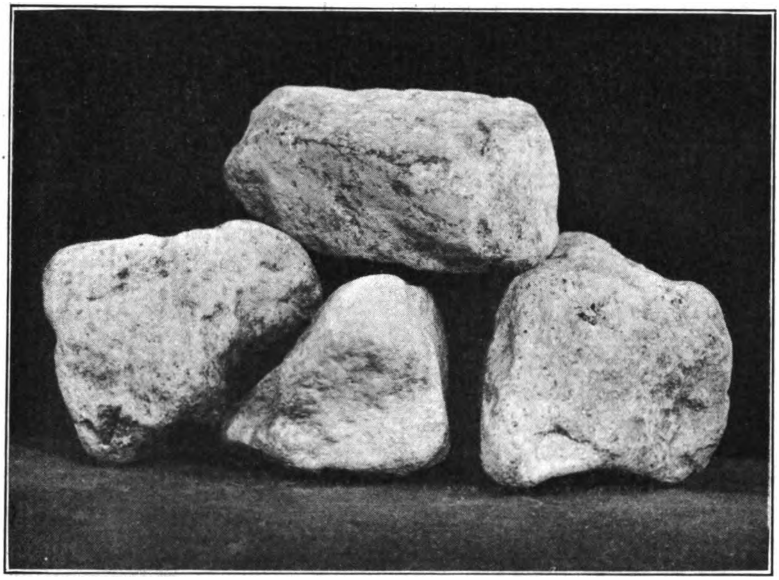

Fig. 6
Pieces of Sandstone before abrasion test.

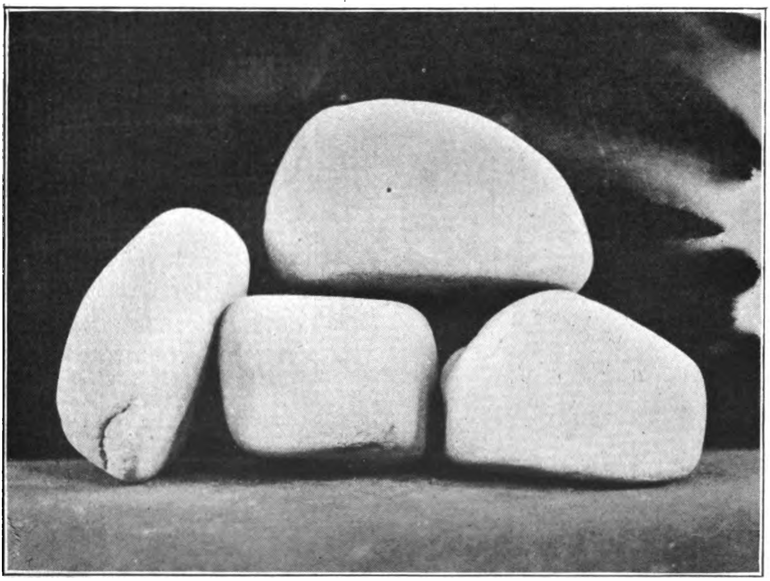

Fig. 7
Sandstone after abrasion test showing wear.

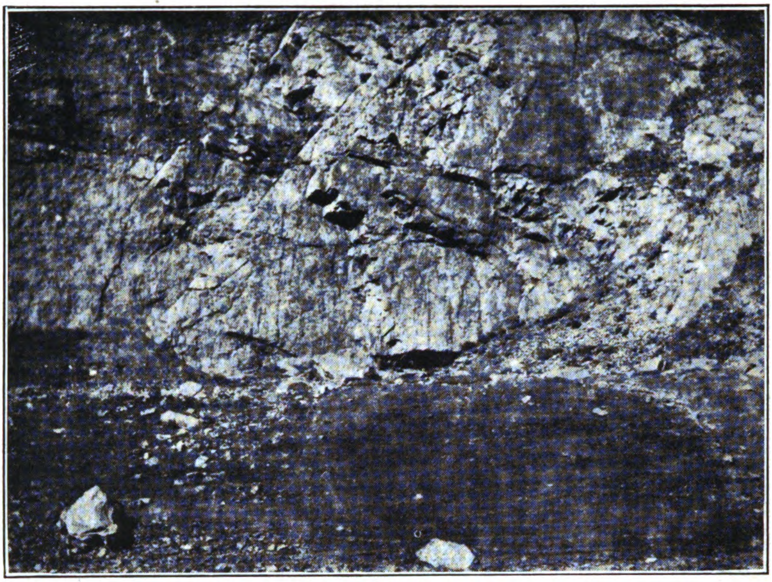

Fig. 14

Limestone Quarry, Fort Douglas Reservation. The Fort road was made of this stone. Coefficient of wear 9.62, toughness 7. No. of test 9.

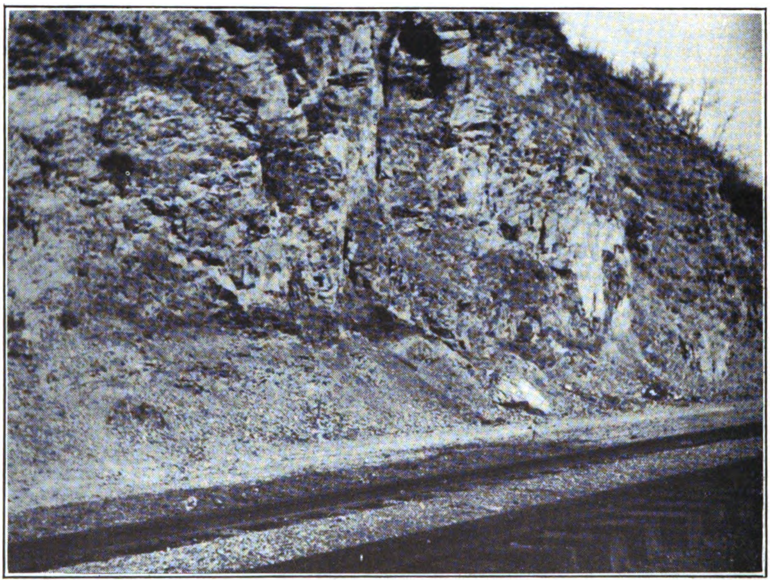

Fig. 15

Limestone in Parley's Canyon. Test No. 12. This stone has a coefficient of wear of 11.3, a toughness of 20.

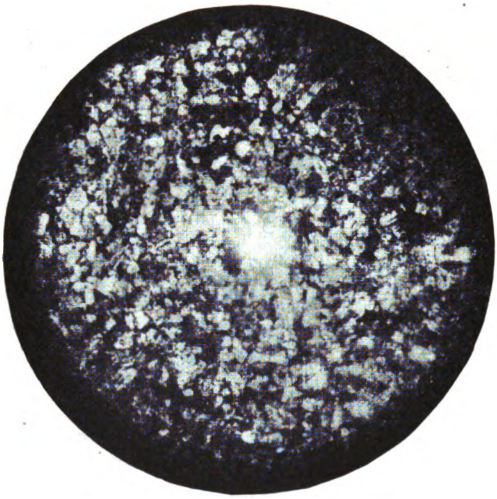

Fig. 8
Bingham Quartzite.

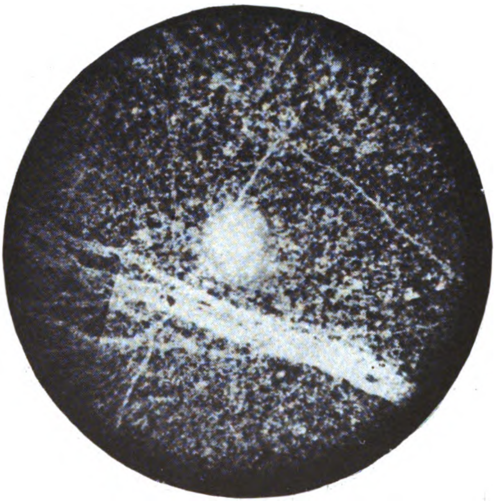

Fig. 9
Calcareous Shale, Dale Station.

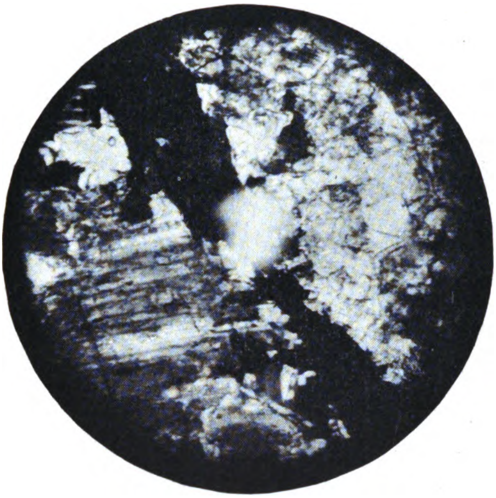

Fig. 10
Granitoid Gneiss.

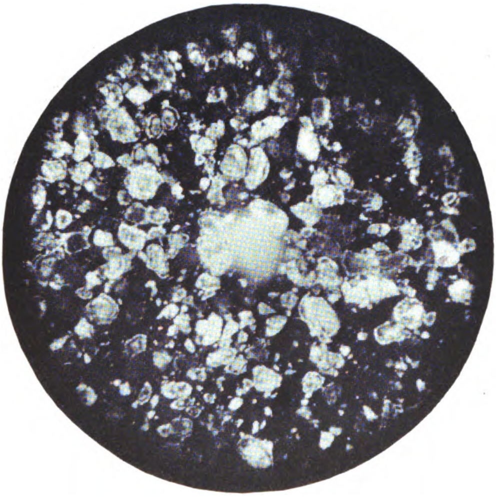

Fig. 11
Sandstone.

of wear. However, some are much more easily worn than others. In toughness, the quartzites show good results, in cementing qualities, they show low results. The dust apparently lacks in adhesion. One sample of slag from the smelter was tested, showing fair results. A microscopic examination of the various rock tested was also made. Some of the sections were magnified and photographed, and are reproduced in cuts 8 to 13. Each mineral of which rock is composed, has distinct characteristics when a very thin section of it is viewed in the microscope. If the microscope is equipped with a polarizer and analyzer for studying the mineral with polarized light, the various minerals show distinct characteristics which are easily recognized.

In the office of public roads in Washington, D. C., a series of investigations on the mineralogical composition of the best rocks for road building was made by Edwin C. Lard, Bulletin No. 31. He draws the following conclusions from his researches:

"1. Igneous and metamorphic rocks, owing to a higher degree of crystallization and a preponderance of silicate minerals, offer a greater resistance to abrasion than nearly all varieties of sedimentary rocks.

"2. The coarse-grained intrusive rocks of the igneous class are harder, but break more readily under impact than the finer-grained volcanic varieties of like mineral composition.

"3. The deleterious effect of atmospheric weathering on the wearing qualities of rocks has been demonstrated.

"4. The cementing value of rocks is, to a certain degree, measured by the abundance of secondary minerals resulting from rock decay.

"5. Metamorphic rocks have, as a rule, a low binding power, owing to a regeneration of secondary minerals and to the effect of heat and pressure. The foliated types part readily along planes of schistosity, and therefore, are not well adapted to road construction.

"6. The quantitive mineral analysis of rocks serves to a certain extent as a measure of their useful properties for road construction."

The action of the weather in distintegrating the rock is a very slow process, but it cannot be neglected. This is especially true where the rock is subjected to alternate freezing and thawing when saturated with water. It is evident that the more porous the rock is, the larger the per cent of water it will absorb and the greater injury would result to the rock when it is subjected to the action of the frost. Any series of tests made on rock for the purpose of comparing their abilities to resist the action of frost, is necessarily long and tedious. Samples of the different kinds of rock were subjected to alternate freezing and thawing, there being thirty-seven separate freezings made. Each time the samples were placed in water and all raised to the boiling point. The results show that, in general, the rock absorbing the most moisture breaks down the most. The shales, sandstones, and some of the limestones being the least able to resist the frost.

The cementing test on the rock dust as made by the Bureau of Public Roads at Washington, is made on rock dust which has been ground from the rock in a ball mill to make a thick dough. After the grinding is finished this dough is moulded and dried and then tested.

The cementing tests on these samples were made as follows: The fine detritus worn from the rock in the abrasion cylinders was moistened and then placed in a mould and the proper pressure was placed on the sample, after which it was dried and tested. The method adopted in these tests shows much lower cementing values than the same rock would by the government method. In the ball mill the rock is not only ground wet, but is also mixed into a more or less tough, plastic dough, and consequently the small adobe shows a greater tendency to cohere than if the material is ground dry and then moistened without being made plastic and then moulded.

This method has the advantage of showing more nearly what effect wetting has on the dust which percolates with the water into the layers of the fine rock on the surface of the road.

Conclusion.

Experience has often demonstrated that the amount of wear, hardness, toughness, weathering, etc., desirable in a rock to be used on a road depends on the amount and kind of traffic, and to a certain extent on the amount of wind and rain which comes in the locality where the road is to be built. Only enough fine dust should be worn from the stone to supply what is carried away, and not enough should be worn to make a layer of mud on the surface. In order to make the best selection in a given case, the results from a large series of tests of the available rock should be made—not only just one test from each quarry or ledge, but several from different parts of it, so that conclusions about the qualities of the rock yielded by the quarry can be accurately drawn. There is little, if any, doubt but that the conclusions that will be drawn of the adaptability of a rock which has been used on a road after years of use, will be the same as the conclusions drawn from the laboratory tests, provided that the traffic was accurately estimated and the road kept in good repair. It is evident that the future use of the more important roads of the State will require a more permanent construction than merely repairing the rough surface, and then we will, more and more, turn our attention to the more permanent and better road that macadamizing will give.

TABLE No. 1
RESULTS OF ABRASION TESTS ON MACADAM ROCK

KIND OF ROCK AND LOCALITY	No.	Wt. each before Abras'n lbs.	Wt. After Abrasion 3 Samples		Wt. Dust		Per Cent Loss	Coef. of Wear	Aver. Coef. of Wear
			lbs.	oz.	lbs.	oz.			
Silicious Limestone (Dry Canyon)	1	11	10	11		5	2.93	14.1	12.0
			10	9		7	4.13	10.08	
			10	10		6	3.53	11.78	
Limestone (City Quarry)	2	11	9	13	1	3	12.21	3.72	3.5
			9	11	1	5	13.5	3.38	
			9	11	1	5	13.5	3.38	
Sandstone (Emigration Canyon)	3	11	8	13	2	3	24.75	2.02	1.8
			8	7	2	9	30.3	1.74	
			8	4	2	12	33.3	1.6	
Shale (Big Cottonwood Canyon)	4	11	10	3		10	6.4	7.07	5.8
			10	6		13	7.98	5.43	
			10	2		14	8.65	5.04	
Limestone (Emigration Canyon)	5	11	10	11		5	2.93	14.1	18.5
			10	12		4	2.33	17.65	
			10	13		3	1.73	23.5	
Silicious Limestone (Emigration Canyon)	6	11	10	5		11	6.65	6.44	6.9
			10	6		10	6.02	7.07	
			10	6		10	6.02	7.07	
Shale (Big Cottonwood Canyon)	7	11	10	9		7	4.15	10.01	11.3
			10	9		7	4.15	10.01	
			10	11		5	2.93	14.1	
Shale (Big Cottonwood Canyon)	8	11	10		1		10.00	4.42	4.5
			10		1		10.00	4.42	
			10	1		15	9.33	4.71	
Limestone (Fort Quarry)	9	11	10	9		7	4.15	10.01	9.6
			10	8		8	4.77	8.85	
			10	9		7	4.15	10.01	
Quartzite (Red Butte Canyon)	10	11	10	13		3	1.73	23.5	20.3
			10	13		3	1.73	23.5	
			10	11		5	2.93	14.1	
Quartzite (Big Cottonwood Canyon)	11	11	10	11		5	2.93	14.1	15.3
			10	11		5	2.93	14.1	
			10	12		4	2.33	17.65	
Limestone (Parley's Canyon)	12	11	10	10		6	3.53	11.78	11.2
			10	10		6	3.53	11.78	
			10	9		7	4.15	10.01	
Quartzite (Parley's Canyon)	13	11	10	13		3	1.73	23.5	27.4
			10	14		2	1.15	35.3	
			10	13		3	1.73	23.5	
Sandstone (Emigration Canyon)	14	11	8	5	2	11	32.3	1.64	1.7
			8	8	2	8	29.3	1.76	
			8	11	2	5	26.6	1.91	
Limestone (City Creek Canyon)	15	11	10	9		7	4.15	10.01	9.6
			10	9		7	4.15	10.01	
			10	8		8	4.77	8.85	
Sandstone (Red Butte Canyon)	16	11	10	4		12	7.33	6.88	5.2
			10	3		13	7.99	5.43	
			10	0	1		10.00	4.42	
Quartzite (Parley's Canyon)	17	11	10	12		4	2.33	17.65	15.3
			10	11		5	2.93	14.1	
			10	11		5	2.93	14.1	
Silicious Limestone (Red Butte Canyon)	18	11	10	14		2	1.15	35.3	24.3
			10	13		3	1.73	23.5	
			10	11		5	2.93	14.1	
Gneiss (Ogden Canyon)	19	11	10	6		10	6.4	7.07	8.3
			10	8		8	4.77	8.85	
			10	8		8	4.77	8.85	
Limestone (Ogden Canyon)	20	11	10	1		15	9.33	4.71	5.9
			10	4		12	7.33	5.88	
			10	6		10	6.4	7.07	
Calcareous Shale (Parley's Canyon)	21	11	9	13	1	3	12.1	3.72	3.7
			9	11	1	5	13.5	3.36	
			9	14	1	2	11.4	3.92	
Calcareous Shale (Parley's Canyon)	22	11	9	14	1	2	11.4	3.92	3.3
			9	11	1	5	13.5	3.36	
			9	4	1	12	18.9	2.52	
Slag (Yampa Smelter)	23	11	10	8		8	4.77	8.85	8.3
			10	8		8	4.77	8.85	
			10	6		10	6.4	7.07	
Quartzite (Bingham Canyon)	24	11	10	8		8	4.77	8.85	8.3
			10	8		8	4.77	8.85	
			10	6		10	6.4	7.07	
Quartzite (Bingham Canyon)	25	11	10	4		12	7.33	5.88	7.6
			10	8		8	4.77	8.85	
			10	8		8	4.77	8.85	
Quartzite (Bingham Canyon)	26	11	10	9		7	4.13	10.01	8.9
			10	8		8	4.77	8.85	
			10	7		9	5.4	7.86	
Granite (Big Cottonwood Canyon)	27	11	10	0	1	0	10.00	4.42	4.5
			9	11	1	5	13.5	3.36	
			10	3		13	7.98	5.43	

TABLE No. 2

RESULTS OF TOUGHNESS TESTS ON MACADAM ROCK

ALL CUBES, .985 INCH. WEIGHT OF HAMMER 2 KILOGRAMS

KIND OF ROCK AND LOCALITY	NUMBER	NUMBER BLOWS THREE SAMPLES A	B	C	MEAN VALUE
Silicious Limestone (Dry Canyon)	1	15	9	14	12.66
Limestone (City Quarry)	2	8	8	5	7.0
Sandstone (Emigration Canyon)	3	4	3	3	3.33
Shale (Big Cottonwood Canyon)	4	14	9	16	13.0
Limestone (Emigration Canyon)	5	5	8	14	9
Silicious Limestone (Emigration Canyon)	6	16	12	16	14.66
Shale (Big Cottonwood Canyon)	7	19	10	6	11.66
Shale (Big Cottonwood Canyon)	8	12	13	15	13.33
Limestone (Fort Quarry)	9	7	6	7	6.66
Quartzite (Red Butte Canyon)	10	38	31	26	31.66
Quartzite (Big Cottonwood Canyon)	11	27	22	16	21.66
Limestone (Parley's Canyon)	12	28	25	7	20.0
Quartzite (Parley's Canyon)	13	26	30	19	25.0
Sandstone (Emigration Canyon)	14	3	4	5	4.0
Limestone (City Creek Canyon)	15	8	4	17	9.66
Sandstone (Red Butte Quarry)	16	5	5	3	4.33
Quartzite (Parley's Canyon)	17	17	20	28	21.66
Silicious Limestone (Red Butte Canyon)	18	12	13	15	13.33
Gneiss (Ogden Canyon)	19	7	8	11	8.66
Limestone (Ogden Canyon)	20	4	7	8	6.33
Calcareous Shale (Parley's Canyon)	21	*			
Calcareous Shale (Parley's Canyon)	22	*			
Slag (Yampa Smelter)	23	9	9	9	9.0
Quartzite (Bingham Canyon)	24	8	5	11	8.0
Quartzite (Bingham Canyon)	25	8	16	17	13.36
Quartzite (Bingham Canyon)	26	21	29	14	21.33
Granite (Big Cottonwood Canyon)	27	5	4	5	4.66

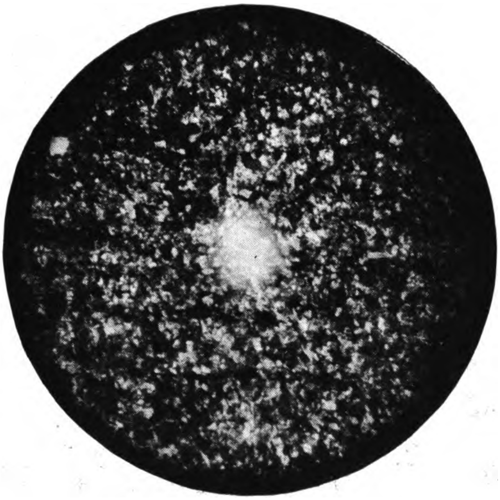

Fig. 12
Limestone (City Quarry).

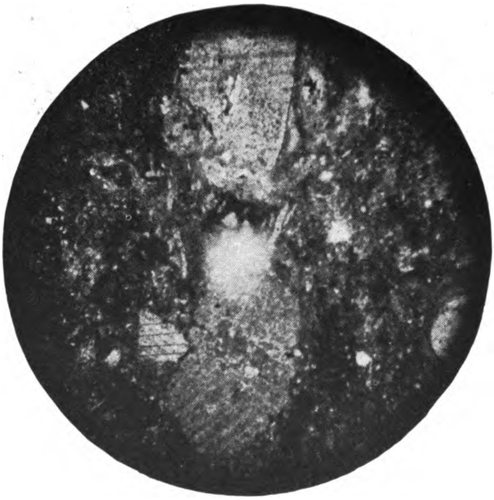

Fig. 13
Limestone (silicious), Dry Canyon.

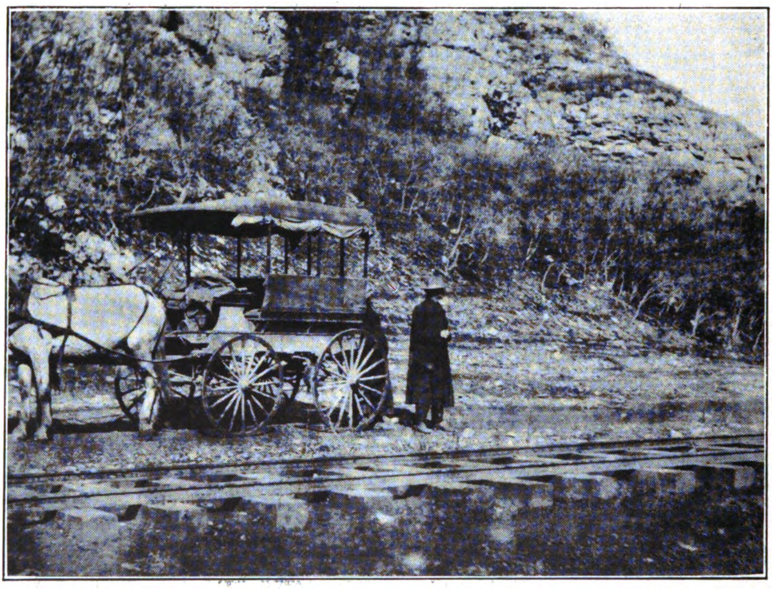

Fig. 16
Emigration Canyon, showing limestone having a coefficient of wear of 6.86 and toughness of 15. Test No. 6.

TABLE No. 3

CEMENTING QUALITY OF ROCK DUST

CYLINDERS .985 INCH. 1 KGM. WEIGHT USED FOR HAMMER
CYLINDERS FOURTEEN DAYS OLD

KIND OF ROCK AND LOCALITY	NUMBER	1 KGM. 1 CM. DROP. NUMBER BLOWS THREE SAMPLES A	B	C	MEAN VALUE
Silicious Limestone (Dry Canyon)	1	27	34	19	26.66
Limestone (City Quarry)	2	3	3	3	3.0
Sandstone (Emigration Canyon)	3	5	5	6	5.33
Shale (Big Cottonwood Canyon)	4	3	3	5	3.66
Limestone (Emigration Canyon)	5	5	4	4	4.33
Silicious Limestone (Emigration Canyon)	6	10	12	8	10.0
Shale (Big Cottonwood Canyon)	7	9	6	7	7.33
Shale (Big Cottonwood Canyon)	8	6	5	6	5.66
Limestone (Fort Quarry)	9	5	5	5	5.0
Quartzite (Red Butte Canyon)	10	3	3	3	3.0
Quartzite (Big Cottonwood Canyon)	11	2	2	2	2.0
Limestone (Parley's Canyon)	12	6	6	6	6.0
Quartzite (Parley's Canyon)	13	7	7	7	7.0
Sandstone (Emigration Canyon)	14	1	1	1	1.0
Limestone (City Creek Canyon)	15	3	3	2	2.66
Sandstone (Red Butte Canyon)	16	6	5	5	5.33
Quartzite (Parley's Canyon)	17	2	2	2	2.0
Silicious Limestone (Parley's Canyon)	18	3	3	3	3.0
Gneiss (Ogden Canyon)	19	3	3	2	2.66
Limestone (Ogden Canyon)	20	2	2	2	2.0
Calcareous Shale (Parley's Canyon)	21	8	9	12	9.66
Calcareous Shale (Parley's Canyon)	22	9	9	9	9.0
Slag (Yampa Smelter)	23	3	3	3	3.0
Quartzite (Bingham Canyon)	24	3	3	3	3.0
Quartzite (Bingham Canyon)	25	5	5	4	4.66
Quartzite (Bingham Canyon)	26	1	1	1	1.0
Granite (Big Cottonwood Canyon)	27	1	1	1	1.0

TABLE No. 4

WEATHERING PROPERTIES OF ROCK

KIND OF ROCK AND LOCALITY	No.	COLOR	WT. IN WATER	WT. IN AIR	Specific Gravity	WEIGHT AFTER SOAKING 96 HRS.	Percent Absorp.	Percent Loss after 37 Freezings and Thawings
Silicious Limestone (Dry Canyon)	1	Gray	1.96	3.21	2.56	3.24	.933	.76
Limestone (City Quarry)	2	Blue	2.28	3.66	2.65	3.68	.548	1.239
Sandstone (Emigration Canyon)	3	Red	1.78	3.08	2.36	3.22	.454	41.15
Shale (Big Cottonwood Canyon)	4	Blue	2.01	3.18	2.67	3.19	.314	22.37
Limestone (Emigration Canyon)	5	Grayish	2.33	3.78	2.60	3.82	1.058	63.98
Silicious Limestone (Emigration Canyon)	6	Gray	6.39	10.24	2.65	10.24	0	5.7
Shale (Big Cottonwood Canyon)	7	Blueish	4.75	7.41	2.78	7.42	.135	.143
Shale (Big Cottonwood Canyon)	8	Gray-Blue	2.42	3.76	2.80	3.77	.266	35.2
Limestone (Fort Quarry)	9	Gray	4.96	7.90	2.68	7.90	0	3.68
Quartzite (Red Butte Canyon)	10	Reddish	3.44	6.53	2.11	5.56	12.22	.828
Quartzite (Big Cottonwood Canyon)	11	White-Gray	3.53	5.65	2.66	5.66	.177	10.53
Limestone (Parley's Canyon)	12	Greenish	2.16	3.49	2.62	3.51	.574	25.56
Quartzite (Parley's Canyon)	13	Reddish	3.18	5.12	2.63	5.12	0	1.478
Sandstone (Emigration Canyon)	14	White	3.72	6.41	2.38	6.61	3.13	25.08
Limestone (City Creek Canyon)	15	Blue-Gray	3.65	5.73	2.75	5.74	1.74	.474
Sandstone (Red Butte Canyon)	16	Red	2.79	4.74	2.56	4.84	2.12	.368
Quartzite (Parley's Canyon)	17	White	2.75	4.43	2.63	4.45	.453	.647
Silicious Limestone (Red Butte Canyon)	18	Greenish	4.92	7.92	2.64	7.94	.253	12.09
Gneiss (Bingham Canyon)	19	Dark Gray	4.28	6.82	2.68	6.83	.146	4.70
Limestone (Ogden Canyon)	20	Blue	2.96	4.63	2.77	4.64	.216	14.42
Calcareous Shale (Parley's Canyon)	21	Gray	2.03	3.25	2.66	3.29	1.23	47.90
Calcareous Shale (Parley's Canyon)	22	Blue	1.5	2.45	2.68	*		81.1
Slag (Yampa Smelter)	23	Black	3.31	4.76	3.28	4.81	1.05	4.31
Quartzite (Bingham Canyon)	24	Gray	3.82	6.43	2.46	6.52	1.39	0
Quartzite (Bingham Canyon)	25	Gray	1.59	2.58	2.6	2.62	1.54	5.18
Quartzite (Ogden Canyon)	26	Dark Gray	2.72	4.56	2.59	4.7	3.07	6.80
Granite (Big Cottonwood Canyon)	27	Gray	4.67	7.49	2.65	7.57	1.07	2.62

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